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Year 1 of the Legacy Survey of Space and Time (LSST): Recommendations for Template Production to Enable Solar System Small Body Transient and Time Domain Science

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Abstract

The Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) will discover ~6 million solar system planetesimals, providing in total over a billion photometric and astrometric measurements in 6 broad-band filters. Rubin Observatory's automated data reduction pipelines will employ difference imaging; templates representing the static sky will be subtracted from the nightly LSST observations in order to identify transient sources, including solar system moving objects. These templates are expected to be generated by coadding high quality images of the same pointing from the previous year's survey observations. The first year of LSST operations will require a different method for generating templates, if solar system discoveries are to be reported daily like Year 2 and beyond. We make recommendations for template production in the LSST's first year and present the opportunities for solar system small body transient and time domain science enhanced by this change.

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1. Introduction

The Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST; Ivezić et al. 2019) will generate an unprecedented data set to explore the solar system's inventory, discovering and monitoring millions of small bodies (LSST Science Collaboration et al. 2009). The Observatory's image subtraction pipeline will identify transient sources in LSST images. This provides the input for Rubin Observatory's Solar System Processing (SSP) pipeline. SSP takes the list of transient sources detected over an approximately two week period and identifies new moving solar system bodies out to ~200 au. The LSST image subtraction pipeline uses a master template representing the static sky, periodically (re)built during Data Release (DR) production. The first set of high fidelity templates is therefore expected post-DR1, a year after observing starts. As a result, moving solar system objects and astrophysical transients would only be identified in the survey's first year of observations at DR1 production, 6 months to a year after the observations were taken. Moving object/transient science would be delayed, starting in LSST Year 2 of operations, when the image subtraction pipeline and SSP could run nightly. A different template generation method is needed for LSST Operations Year 1 (LOY1). Rubin Observatory is evaluating options for producing a special set of LOY1 templates (potentially on a monthly or weekly basis) (Graham et al. 2019). In this Research Note, the Rubin Observatory LSST solar system Science Collaboration (SSSC) recommend LOY1 template acquisition strategies and highlight the opportunities for high impact transient and time domain solar system science available if small body discoveries can be reported nightly from the start of the survey.

2. Recommendations for LSST Year 1 Operations (LOY1) Template Generation

We advocate for LOY1 template options that allow the Rubin Observatory's SSP pipelines to run daily at the start of operations, even if these templates result in noisier image subtraction compared to DR1. Discovery and orbit characterization of the solar system's small body reservoirs and detection of cometary activity are the highest priorities in the SSSC's science roadmap (Schwamb et al. 2018). To maximize the chances of discovery and rapid reporting to the planetary community, sky coverage is preferred over filter completeness. Solar system objects are brightest in *g*, *r*, and *i* filters; we ask for LOY1 template generation to be prioritized in these filters. If any commissioning tests are agnostic to filter and pointing, we ask that they be planned to maximize the number of pointings where LOY1 templates can be produced. This strategy also complements the LOY1 template strategy recommended to enhance astrophysical transient science (Hambleton et al. 2020; Street et al. 2020).

3. LOY1 Small Body Transient and Time Domain Science

We highlight the solar system transient events and small body discoveries where opportunities to obtain near real-time spectroscopic, photometric, and astrometric follow-up observations would significantly benefit from daily SSP processing in LOY1. Without LOY1 template generation, follow-up opportunities for ~10% of the total LSST detections in each of the following cases below would be missed. The majority of these cases are rare or have low occurrence rates. Thus, the potential lack of real-time solar system discoveries in LOY1 could have a significant impact.

3.1. Interstellar Objects

The LSST is expected to detect several interstellar objects (ISOs), rogue planetesimals on hyperbolic orbits passing through our solar system, per year (e.g., Rice & Laughlin 2019). ISOs provide rare opportunities to sample planet formation around other stars, using the same observational techniques used with solar system bodies. As with 1I/'Oumuamua, there may only be a few weeks of time to observe these rare objects ('Oumuamua ISSI Team 2019); immediate follow-up after discovery is crucial. Without daily SSP detections in LOY1, ISO discoveries will likely be too faint to observe by the time they are discovered at DR processing.

3.2. Earth Impactors and Mini-Moons

Potential Earth impactors discovered by the LSST will need rapid astrometric follow-up to determine impact probabilities. Daily LSST solar system detections would facilitate prompt rapid warning to the predicted impact zone, enable pre-impact studies of the object, and increase the likelihood of recovering meteorite fragments, as was done for 2008 TC3, 2014 AA, and 2018 LA (Farnocchia et al. 2016, 2017; Jenniskens et al. 2021). Mini-moons are near Earth asteroids temporarily captured in orbit around Earth. Due their close proximity to the Earth, these objects probe the asteroid belt on scales much smaller than can be observed directly within the belt today. Mini-moons are observable for a limited time; rapid follow-up is crucial to characterize mini-moons before they escape Earth's orbit (e.g. Bolin et al. 2020; Fedorets et al. 2020).

3.3. Disruption/Fragmentation Events and Cometary Outbursts

In LOY1, the LSST will observe disruption/fragmentation events and cometary outbursts within the asteroid, comet, and Centaur populations. The timescales for needed follow-up observations are short (hours to days), and the data cannot be obtained if these events are not discovered until later. The few asteroid disruptions and comet fragmentation events observed to date have been extremely diverse (e.g. Ishiguro et al. 2016; Hainaut et al. 2019). The LSST could have significant impact, with real-time solar system alerts enabling prompt community follow-up to probe the nature of these processes.

3.4. Stellar Occultations

Combining the LSST's 10 mas astrometry of previously known solar system objects with Gaia data will enable highly accurate stellar occultation predictions in LOY1 (Camargo et al. 2018). These events can be observed by ground campaigns in order to measure sizes/shapes to high accuracy (down to a few km) and also identify rings, dust structures, or atmospheres around these bodies (e.g. Braga-Ribas et al. 2014; Buie et al. 2020).

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